PRISM Cruises: Developing a Database to Evaluate Interannual Variability in Puget Sound
Part 1: Temperature and Salinity 1998-2002
Part 2: Dissolved Oxygen 1998-2002

Jonathan Kellogg, Noel Gray, Mitsuhiro Kawase, Mark Warner *and* ***Jan Newton***
University of Washington, School of Oceanography

Abstract
The Puget Sound Regional Synthesis Model (PRISM) was established in 1998 to develop a comprehensive baseline model for the natural and human environment of the Puget Sound drainage basin. Our work focuses on understanding estuarine circulation through variability in the hydrographic properties. The University of Washington School of Oceanography in conjunction with Washington State Department of Ecology have utilized the *R/V Thomas G. Thompson* to sample 39 stations in four regions of Puget Sound; Hood Canal, Main, Whidbey and South Basins—as well as the adjacent eastern Strait of Juan de Fuca (Figure 1). The four-day cruises have occurred semi-annually in June and December and have resulted in a 5-year data set, which includes physical, chemical, and biological measurements of the water column. We examine temperature, salinity and dissolved oxygen concentration and correlate them with climatological factors and physical processes. Upon analysis of this data set, important changes in the water column stand out. These include surface salinities influenced by river discharge, air/sea-surface temperature correlation as well as changes in non-conservative concentrations such as dissolved oxygen. Existing and future data will be used to enhance empirical observations and the accuracy of circulation models for Puget Sound.

Surface Air Temperature
Smith Island and West Point air temperature anomaly plots follow a similar trend throughout the time series (Figure 2). Air temperature correlates well with the observed sea surface temperature (SST). The Smith Island temperature record reflects the changes in SST that were measured at stations 24 and 22 in all cruises. Air temperature is anomalously high when the water temperature is high in June 1998 as well as in June 2002. Air temperature is also low at Smith Island when SST is low in December 2000 and 2001. The West Point temperature record corresponds with PRISM stations 28 and 29 in the Main Basin. West Point air temperature is anomalously high when the water temperature is high in June 1998, as well as in June 2002. These two observations are above the standard deviation for the 5-year record. The interaction between Puget Sound and the atmosphere acts to moderate temperature fluctuations within the region. The temperature variation was less than 4C, which is considerably less than further inland stations.

Pacific Decadal Oscillation Index
The Pacific Decadal Oscillation (PDO) Index is a temperature related oscillation in the North Pacific (Figure 3). Positive values for the index indicate warmer waters off the coast of North America and colder than normal waters in the open North Pacific whereas negative values indicate the opposite scenario. Puget Sound waters closely correlate with the PDO index roughly three months prior to the sampling time. This delay exists because the coastal Pacific Ocean condition takes time to propagate from the mouth of the Strait of Juan de Fuca to the mouth of Admiralty Inlet. This index explains the warm water throughout the Sound in June 1998 and the much colder temperatures seen in the water column in December 1999 and 2000. Though the index did not change sign in the period just before the December 1998 and June 2002 PRISM Cruises, the weakened negative condition is exhibited in slightly warmer waters at Hein Bank than is seen in December 1999, 2000 or 2001. The positive index in late 2000 into 2001 is not exhibited in the water column either inside or outside the Sound because the condition in the Pacific Ocean did not exist three months before the cruise.

Streamflow
We looked at the four dominant rivers within the Sound that influence the three basins (Figure 4). These included the Skokomish River at the head of Hood Canal, the Puyallup River near Dalco Passage, and the Skagit and Snohomish Rivers at the head of Whidbey Basin and Possession Sound, respectively. There is an inverse relationship between the monthly streamflow anomaly and the salinity of the upper 20 meters. Upon examination of the streamflow anomaly, it is expected that there is low salinity throughout 1999 because of the large volume of fresh water entering all the basins. A reduction in flow leads to increasing surface salinity in June 2001, which begins to decrease again as the streamflow increases through the early months of 2002. In Whidbey Basin it is important to note that both the Skagit and Snohom-

ish rivers greatly influence the salinity. The low salinities of station 1, in the Whidbey Basin transect, reflect the input of water from the Snohomish River which is located to the east of this section. This large influx of fresh water can be seen draining into Main Basin at Triple Junction in response to tidal forcing.

Dissolved Oxygen

Percent saturation is a useful parameter because it eliminates the temperature and salinity effects on dissolved oxygen (DO) concentration and highlights under/super-saturations in the surface layer (Figure 5A). A plot of percent saturation for one station, within each basin and each year gives a snapshot of the spatial and temporal variability. In general, super-saturations occur in June and under-saturations in December. Main and Whidbey Basins show relative stability, in that the standard deviation is less than 19 percent whereas Hood Canal is greater than 25 percent. Surface chlorophyll-*a* concentration is then plotted to see if the under/super-saturations can be understood in terms of primary production (Figure 5B). Whidbey Basin gives the best indication of a possible seasonal cycle because its concentrations are highest in June and lowest in the December for data from June 1998, to December 2001. For waters below 20 decibars, which are not in contact with the atmosphere, an apparent oxygen utilization (AOU) is calculated (Figure 5C). This quantity gives the amount of oxygen consumed via the respiration of organic matter since a parcel left the surface. The plot shows Hood Canal having the largest AOUs. During this time interval, the seasonal frequency does not appear to dominate as much as it does in the surface saturation plot. The minimum to maximum AOU values may give an indication of another cycle, namely the residence time of the basin. Using AOU=R*t, where R is the respiration rate and t is time: if R is assumed constant and the initial concentration for each basin is the same (e.g. source water via Admiralty Inlet) then larger AOU values would indicate longer residence times. In this case, Hood Canal would have the longest residence time, followed by Whidbey Basin and then Main Basin.

Conclusion

PRISM is working towards the end goal of understanding Puget Sound's physical status in terms of discrete, quantifiable parameters. The variations indicate correspondences between the Sound and its physical surroundings. There is a direct relationship between sea surface temperature and this interaction moderates the regional climate. Streamflow fluctuations are inversely related to the surface salinity and surface salinity affects the dissolved oxygen concentration as well as the biology, which produces and consumes dissolved oxygen. The cruises, to date, have initiated a data set, which already offers insight into the physical mechanisms that drive change. In order to utilize the data set's potential, data analysis is coupled with other data sets such as the PDO Index, streamflow and air temperature. These indices have a much finer temporal scale and the PRISM data set is limited by a large sampling interval. To impede this reality, PRISM also utilizes mathematical modeling to "fill in" the gaps as well as predict future changes.

Figures

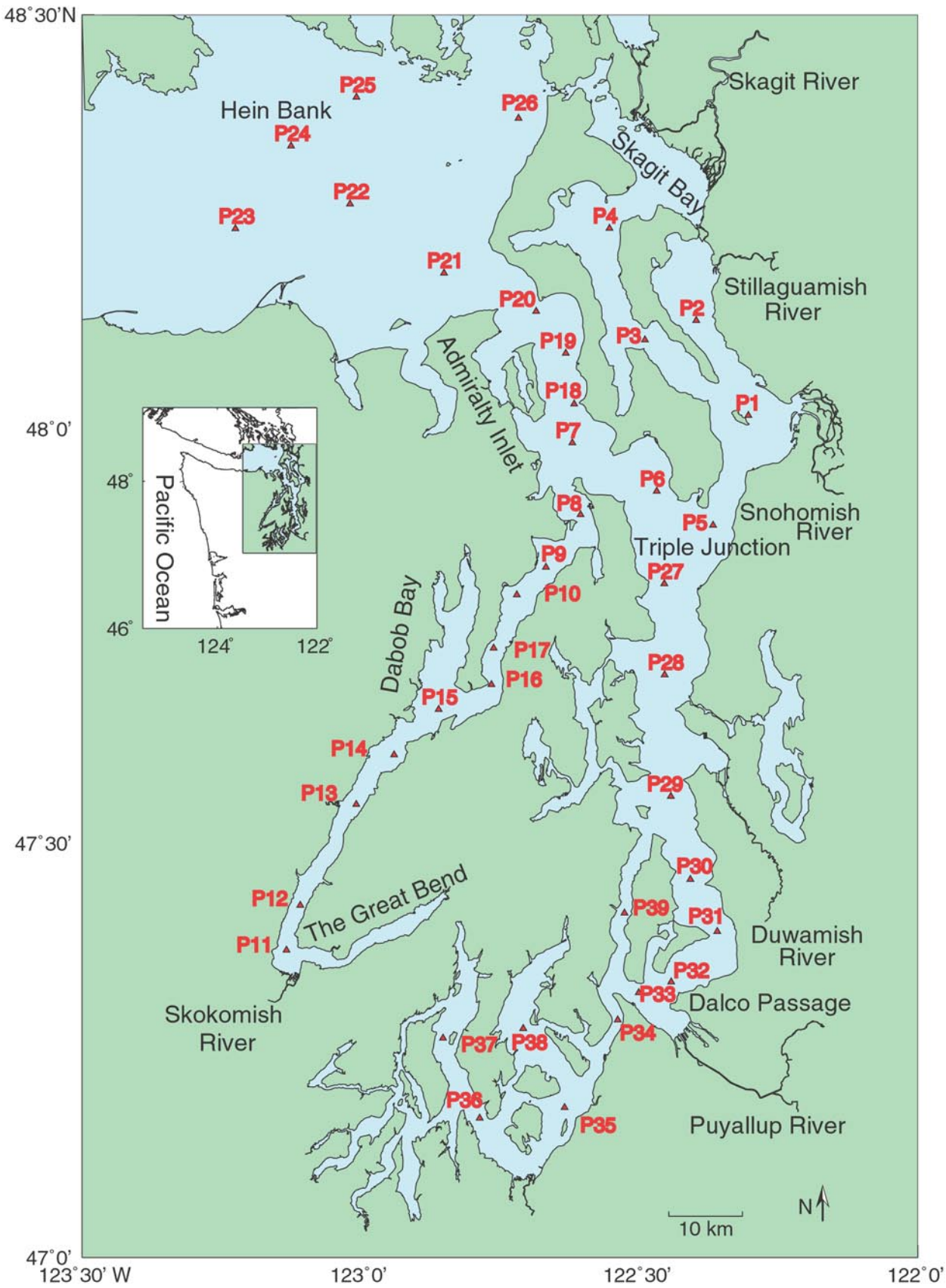

Figure 1. Map of PRISM stations located in Puget Sound, Washington.

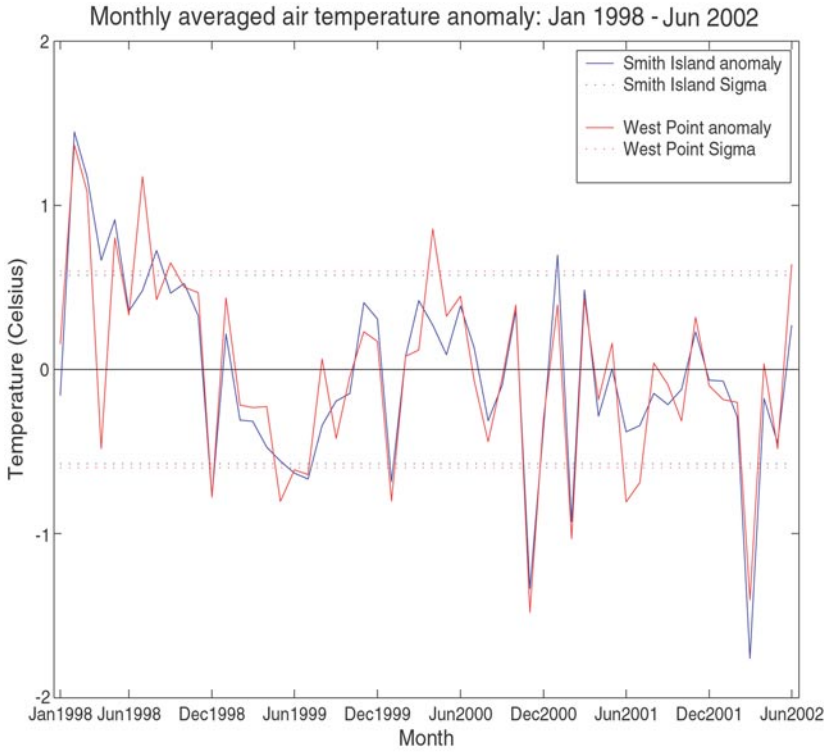

Figure 2. Monthly averaged air temperature anomaly record for Smith Island and West Point, Washington from January 1998 through June 2002. Standard deviation for the record is given with the dashed line. From NOAA.

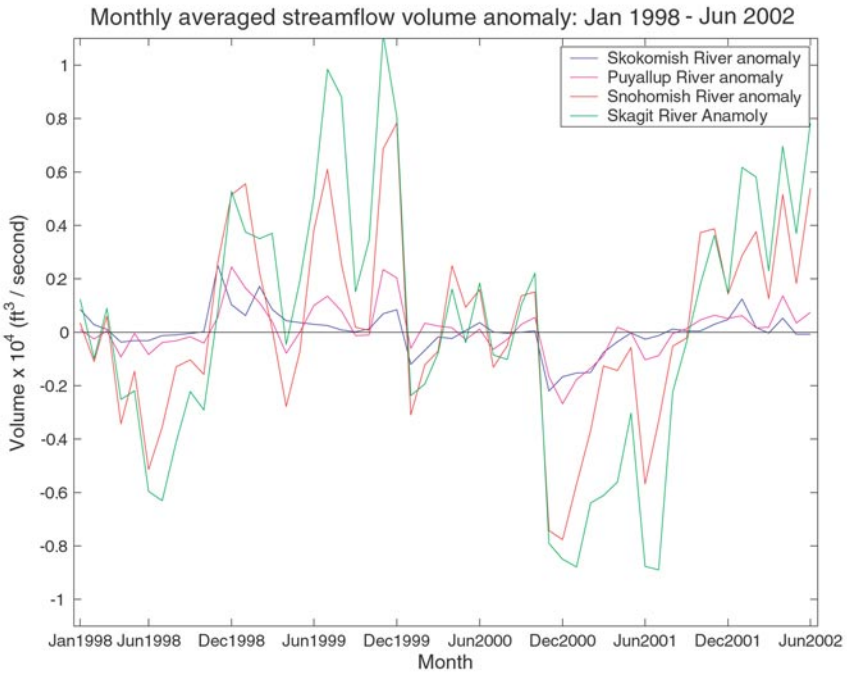

Figure 3. Monthly averaged streamflow anomaly record for the Skokomish, Puyallup, Snohomish and Skagit Rivers in Washington from January 1998 through June 2002. From USGS.

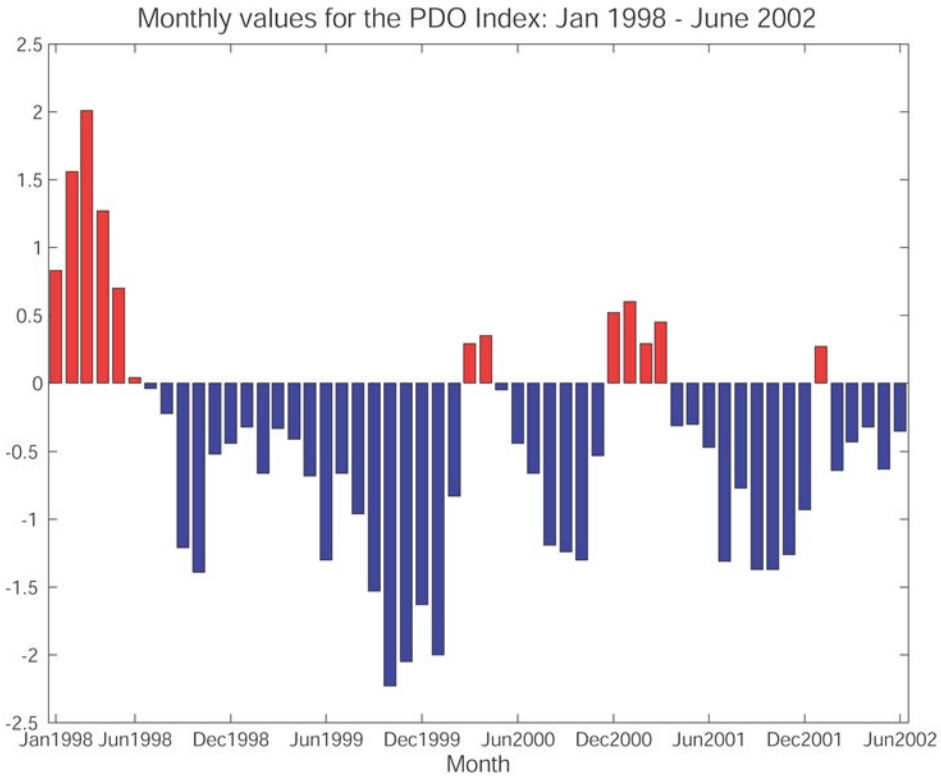

Figure 4. Monthly values for the PDO index for the period from January 1998 to June 2002. From Mantua and Hare.

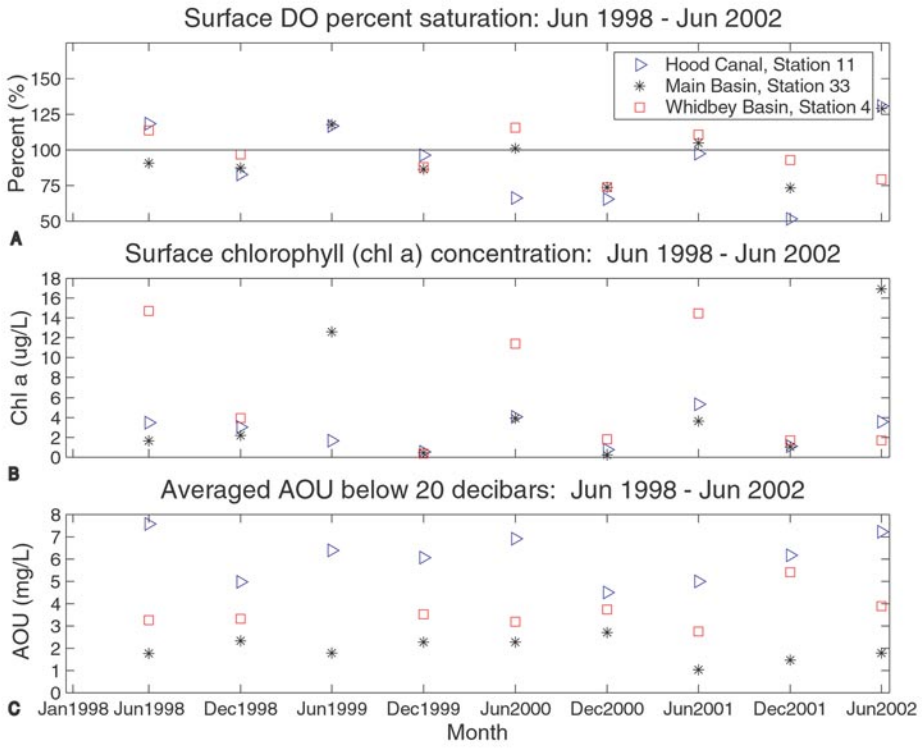

Figure 5. (A) Surface dissolved oxygen (DO) percent saturation (B) Surface chlorophyll concentration and (C) Averaged AOU below 20 decibars for three stations in Puget Sound, Washington, from June 1998 to June 2002.